Glycidyl Esters. IV.[1] Hydration of Glycidyl Stearate

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Abstract

The acid-catalyzed conversion of glycidyl stearate to monostearin has been investigated. By use of an essentially nonaqueous reaction medium and a two-step procedure, high yields of monostearin were obtained at 15–20C in brief reaction periods, while avoiding ester hydrolysis. Distearin was found to be a by-product. The influence of solvent, reaction temperature, and type of acid catalyst upon the relative amounts of monostearin and distearin produced were studied. A possible reaction path leading to the formation of distearin is proposed.

Introduction

DURING THE COURSE of our investigations into the synthesis and reactions of glycidyl esters of fat-derived acids, a practical method of converting these esters to the corresponding glycerides was desired. We chose to concentrate our efforts upon studying the hydration of a model compound, namely glycidyl stearate. Beyond general statements to the effect that such hydrations are feasible (1,2), we could find little evidence that this problem has been studied previously in any detail. On the other hand, there is considerable wealth of published information concerning the hydration of oxirane compounds which do not contain ester functions. Much of this work has been summarized capably and evaluated critically by Parker and Isaacs (3).

The commonly used method of converting epoxides to vicinal glycols, i.e., prolonged reflux in an aqueous acid medium, was unsuitable to the accomplishment of our purposes, both because glycidyl stearate is quite insoluble in hot water and because the hot aqueous acid would tend to hydrolyze the ester function which we wished to preserve. Since acid catalyzed hydration of epoxides and hydrolysis of esters are competing reactions which proceed along rather analogous reaction paths, it was necessary to find conditions which would favor hydration over hydrolysis.

The desired degree of selectivity was achieved by performing the reaction in a two-step sequence. Glycidyl stearate was dissolved in a nonaqueous, but water-miscible solvent, and sufficient acid to protonate the oxirane function was added at room temperature or below. Water was then added, and, after sufficient time was allowed for hydration, the reaction was stopped by pouring the mixture into benzene. In most runs a period of 5–10 min for each step was sufficient to effect a complete disappearance of epoxide, usually without formation of detectable amounts of stearic acid.

Nishiyama et al. (4) reported the hydration of esters of epoxidized fatty acids both in heterogeneous and in homogeneous (acetone) media. In a certain general way our work parallels and complements that of the Japanese workers, who concentrated their efforts on measuring the rate of disappearance of epoxide functions rather than on identification of the reaction products.

We chose the latter approach. Chromatographic separation of the crude reaction products according to the method of Quinlin and Weiser (5) revealed that the hydration reaction was considerably more complex than had been anticipated. Along with the desired product monostearin, considerable quantities of distearin and glycerol were also produced in many of the runs. At times, other by-products appeared as well. Some of these remained unidentified, while others can be traced to an interaction between solvent and glycidyl stearate. The amount of distearin formed varied with the solvent used, with the acid employed, and with the reaction temperature, so that in some experiments the amount of distearin exceeded 50% of theory.

Experimental Procedures and Data

Glycidyl Stearate. The glycidyl stearate used throughout this study was prepared as described previously (6). Oxirane oxygen (7): 4.42%. Theory: 4.69%.

Monoölein. Glyceryl oleate was prepared by way of the isopropylidene derivative according to the method of Fischer (11). The crude product was purified by the same chromatographic method used for purification of crude hydration products. The purified material had an iodine value (I.V.) of 70.7 (theory: 71.2).

Acetone. Acetone, ACS grade (J. T. Baker Chemical Company) was dried over magnesium sulfate, filtered, and distilled from magnesium sulfate.

Benzene. Benzene, ACS grade, was dried over Drierite and filtered.

1,4-Dioxane. 1,4-Dioxane (Eastman—practical) was purified according to method of Hess and Frahm (8).

Other Solvents. Methyl acetate (Eastman—anhydrous) and methanol (Baker—ACS grade) were used as received.

Hydration Procedure. The following example is representative of the hydration procedure employed. Variations of this procedure are shown in Tables I–IV.

A solution of 5.00 g glycidyl stearate in 60 ml 1,4-dioxane was placed in a 200 ml 3-neck flask, equipped with mechanical stirrer, thermometer, addition funnel and external cooling bath, and was cooled to 15C. To the well-agitated solution was added at a rapid dropwise rate a solution of 2.0 g conc. H_2SO_4 in 15 ml 1,4-dioxane (addition time 2 min). After stirring the mixture for 8 min after completion of acid addition, 10 ml distilled water was added at a rapid dropwise

TABLE I

Hydration of Glycidyl Stearate in 1,4-Dioxane.[a]
Effect of Reaction Temperature

| Reaction temp C | Wt[b] g | Crude product | | | |
| | | Concentration (%) | | Yield (%) | |
		Mono-stearin	Di-stearin	Mono-stearin	Di-stearin
15	4.95	89.0	8.0	87.8	9.1
45	5.38	35.0	49.0	37.5	60.0
90	4.64	35.0	58.0	32.2	61.4

[a] Catalyst: 95% H_2SO_4.
[b] Starting material: 5.00 g glycidyl stearate.

TABLE II

Hydration of Glycidyl Stearate.[a] Effect of Variation of Solvents

Solvent	Reaction temp C	Yield (%)		
		Mono-stearin	Di-stearin	Other
1,4-Dioxane	15	87.8	9.1	......
1,4-Dioxane/benzene	15	23.7	54.3	......
Acetone	18	45.4	......	45.2 [b]
Methanol	37	18.0	......	52.0 [c]
				10.0 [d]
Methyl acetate	20	30.0	56.3	......
Benzene	20	18.0	56.5	......

[a] Catalyst: 95% H_2SO_4.
[b] Isopropylidene glycerol stearate.
[c] 3(2)-Hydroxy-2(3) methoxypropyl stearate.
[d] Methyl stearate.

rate (addition time 1.5 min) followed by a further period of stirring for 8.5 min. During the entire sequence the temperature was maintained at 15C ± 1. The reaction mixture was poured into a separatory funnel containing 200 ml benzene. The aqueous acid phase was withdrawn, and the benzene solution was washed with 25 ml $NaHCO_3$ solution (5%) and then with 50 ml water. The benzene solution was dried over Drierite and evaporated on the steam bath under nitrogen to give an oily residue, 4.95 g; oxirane oxygen <0.1%, which solidified on cooling. A sample of the crude material (1.00 g) dissolved in 15 ml $CHCl_3$ was adsorbed on 30 g silica gel (Davison #923) equilibrated overnight against air. Elution with benzene-ether mixtures gave 0.08 g distearin and 0.89 g monostearin. Both compounds were identified by their infrared spectra. The combined aqueous phases from the crude product work-up did not contain detectable amounts of stearic acid.

Further Analysis of Monostearin Fractions. The combined monostearin fractions from several experiments were passed through a silica gel column to give purified monostearin, mp 77.0–78.5C, the I.R. spectrum which was identical with an authentic sample prepared by the acetone glycerol method.

Anal. Calc'd. for $C_{21}H_{42}O_4$: C, 70.34; H, 11.81; OH, 9.48; Sap. No. 156.5. Found: C, 70.80; H, 11.81; OH, 9.60; Sap. No. 155.2.

Periodate analysis of this sample according to the method of Pohle and Mehlenbacher (9) gave an α-monostearin content of 95.9%.

Hydration in Methyl Acetate. Analysis of Diester Fraction. Hydration of glycidyl stearate in methyl acetate followed by chromatography of the crude product gave a diester fraction mp 74.9–75.9C, which was analyzed to find evidence for or against the presence of the transesterification product glyceryl stearate acetate ($C_{23}H_{44}O_5$).

Anal. Calc'd. for $C_{23}H_{44}O_5$: C, 68.96; H, 11.07; OH, 4.24; Sap. No. 308.1. Found: C, 75.20; H, 12.33; OH, 2.67; Sap. No. 179.4. Calc'd. for $C_{39}H_{76}O_5$ (distearin): C, 74.94; H, 12.26; OH, 2.72; Sap. No. 179.5.

Hydration of Glycidyl Stearate in the Presence of Monoölein. Glycidyl stearate (5.00 g) and monoölein (5.00 g) (10) were dissolved in 100 ml methyl acetate. A solution of 3.6 g concd sulfuric acid in 9 ml methyl acetate was added to the vigorously stirred solution at 20C over a period of 7 min. The slurry which formed was stirred at 18–20C for an additional 8 min. Distilled water (12 ml) was then added over a period of 2 min and the slurry agitated at 10–20C for an additional 13 min before pouring it into 200 ml benzene. The acid layer was drawn off, and the benzene solution was washed twice with 5% potassium bicarbonate solution (25 ml) and once with water (50 ml). The organic phase was dried over calcium sulfate and evaporated to a semisolid residue (8.82 g). The theoretically obtainable weight of crude product is 10.25 g assuming that the glycerol formed is retained.

The crude product was separated by silica gel column chromatography into a diglyceride fraction (50.3% of the crude) and a monoglyceride fraction (34.3%). The diglyceride fraction had an I.V. of 43.7 (theory for glyceryl oleate stearate 40.7) while the I.V. of the monoglyceride fraction was 33.6. Total oleate accounted for in the two fractions was 79.3%.

Results

High yields of monostearin were obtained when glycidyl stearate, dissolved in 1,4-dioxane, was treated at 15C with about a 50% molar excess of 95% sulfuric acid for ten min, followed by treatment with about 30 times the stoichiometrically required amount of water for another ten min at the same temperature. The reaction was stopped by pouring the mixture into excess benzene and withdrawing the aqueous acid phase. The crude product, isolated after washing, drying, and evaporating the benzene solution, was separated into its major components by chromatography on a silica gel column.

Variation in reaction temperature affects the relative amounts of monostearin and distearin obtained as shown in Table I. This temperature effect is more pronounced at lower than at elevated temperatures and has also been observed when acetone was used as solvent. The results would seem to indicate the desirability of employing even lower reaction temperatures to increase the monostearin yield. However, below 15C the solubility of the starting material in 1,4-dioxane is poor.

Table II illustrates the use of a variety of solvents as reaction media and clearly shows the influence which the solvent exerts on the final outcome of the hydration reaction. Use of 1,4-dioxane gave highest monostearin yields, the results being the same whether the acid was added to a solution of glycidyl stearate in dioxane or whether an inverse addition (glycidyl stearate solution added to acid) was utilized. However, a change in solvent character after the first step in the hydration, i.e., after protonation, led to entirely different results, as shown by the second example in Table II (marked 1,4-dioxane/benzene). In this experiment the protonation step was carried out in dioxane in the normal manner, but was not followed immediately by water treatment. Instead, the protonated mixture was poured into benzene first and then treated with water. A dramatic change in product composition was accomplished by a rather minor procedural modification. Use of acetone as reaction medium gave isopropylidene-glycerol stearate (IGS) as the principal by-product. The presence of this compound, formed by the interaction of acetone and glycidyl stearate, is not necessarily objectionable since it is readily hydrolyzed to monostearin (11,12). Willfang (13) and Bogert and Roblin (14), as well as others, have previously reported the formation of 1,3-dioxolanes from the reaction of epoxides with aldehydes and ketones in the presence of acid catalysts.

Methanol was unsuitable as solvent for the hydration reaction since its low solubility for both starting material and reaction products necessitated an undesirably high (37C) reaction temperature. The principal product in this case was the monomethyl ether of monostearin accompanied by smaller amounts of monostearin and methyl stearate. Use of methyl acetate or benzene as solvents gave distearin predominantly. Similar results were obtained in methylene chloride, nitromethane, and diethyl ether. In tetrahydrofuran, on the other hand, about 47% of the starting material remained unreacted at the end of the normal period, while the remainder was converted chiefly to distearin.

H_2SO_4 Concentration %	Ratio H_2SO_4:H_2O	Wt[c] g	Crude product			
			Concentration (%)		Yield (%)	
			Monostearin	Distearin	Monostearin	Distearin
100	......	2.80	11.0	76.0	6.1	48.6
95	3.4:1	4.95	89.0	8.0	87.8	9.1
84.5	1:1	4.20	38.0	54.0	31.9	51.8
73.1	1:2	4.25	60.0	32.0	55.2	33.7
64.5	1:3	4.61	65.0	27.0	55.0	26.2
57.6[b]	1:4	4.26	52.0	23.0	44.2	22.4

[a] Reaction temperature: 15C.
[b] 18.7% Glycidyl stearate was recovered unreacted.
[c] Starting material: 5.00 g glycidyl stearate.

The series of experiments listed in Table III demonstrates the need for keeping the water content of the reaction mixture low during the protonation step in order to get high yields of monostearin. Water added by diluting the sulfuric acid catalyst not only gave rise to relatively greater amounts of distearin, but also decreased the overall reaction rate. However a linear relationship between water content and yield of either monostearin or distearin was not observed. At sulfuric acid concentrations of less than 60%, considerable amounts of glycidyl stearate remained unreacted at the end of the normal reaction period. It was further observed that employment of relatively dilute catalyst solutions gave rise to a previously unencountered by-product (mp 141–141.5C) which was soluble in hot methanol, ethanol, and water, but insoluble in all other solvents tried. This product has been identified tentatively as sodium stearoxyglyceryl sulfate. On the other hand, complete absence of water also led to poor yields. In this case another side reaction, probably polymer formation, was at fault.

The water dilution studies just described were carried out using 1,4-dioxane as solvent. A number of the experiments were repeated in acetone with equivalent results.

Discussion

It is apparent from the preceding paragraphs that the conversion of glycidyl stearate to monostearin can be carried out in high yields and with a minimum of complications from by-products. It is also apparent that the reaction is favored by low reaction temperatures, use of concentrated strong acids as catalysts, and employment of certain solvents, while under less advantageous conditions competing reactions predominate.

One competing reaction which is of concern when esters are treated with aqueous acids, i.e., ester hydrolysis, seemed to be of little importance under the moderate conditions employed here, as judged from the absence of detectable amounts of stearic acid among the products in most experiments. Thus, one of the aims of the present work was achieved. On the other hand, lack of evidence for ester hydrolysis caused speculation regarding the reaction responsible for the formation of distearin in these experiments.

The possibility that the diester is produced as a result of a secondary reaction of the hydration product monostearin was examined first. Privett (15) noted that monostearins prepared by the acetone-glycerol method, but not those synthesized by other methods, contained impurities which catalyzed the decomposition of the monoglycerides to glycerol and fatty acids, and which under certain conditions gave rise to some diglycerides. Crossley et al. (16) detected small amounts of monostearin after heating distearin for 3 hr at 165C and Grün (17) reported

the disproportionation of monoglycerides at elevated temperatures. All these reported disproportionations occurred at temperatures considerably above those encountered in our studies.

The possibility that the formation of distearin in our experiments was due to an acid-catalyzed acyl exchange (18) between two molecules of monostearin was dismissed when it was shown experimentally that pure monostearin, dissolved in acetone containing sulfuric acid did not give rise to distearin. Furthermore, such a secondary autoreaction would be time-dependent, so that the distearin yield should increase with reaction time. In fact, however, the amount of distearin remained constant when the reaction period was lengthened.

Our attention was next focused upon the possibility that the diester was the product of a reaction of monostearin with glycidyl stearate (or protonated glycidyl stearate). Such a hypothesis required that glycidyl stearate, rather than monostearin, donates the acyl group, since monostearin by itself had already been shown to be incapable of forming distearin under prevailing conditions. Moreover, it had been demonstrated that methyl acetate, when used as the solvent in the hydration reaction, also did not provide acyl groups; the resulting diester fraction containing only distearin (see Table II). On the other hand, methyl stearate was formed in what most likely was an alcoholysis reaction, when the hydration of glycidyl stearate was carried out in methanol. These facts suggested that if distearin arises from an alcoholysis reaction between monostearin and glycidyl stearate, the latter must possess some structural feature which is absent in methyl acetate and in monostearin.

The readiness with which glycidyl stearate acts as an acyl donor may be rationalized on the basis of the cyclic structure A in which the acyl carbon assumes a positive charge:

A
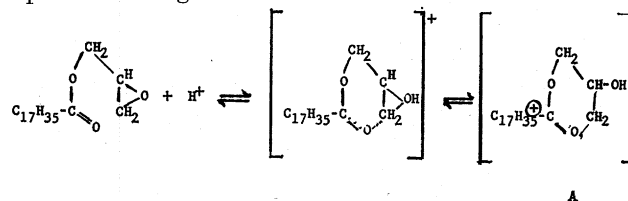
Intermediate A is capable of reacting with water to give monostearin or with monostearin to give distearin:
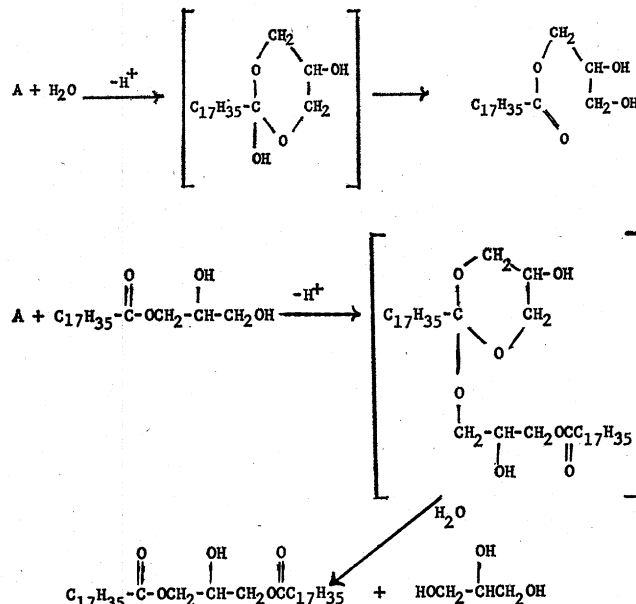
TABLE IV
Hydration of Glycidyl Stearate. Catalysis by Various Acids

Acid			Reaction temp C	Yield (%)		
Name	Grade	Amount moles/ mole epoxide		Mono- stearin	Di- stearin	IGS[a]
Naphthalene- 2-sulfonic acid	Monohy- drate solid	2.7	20 [c]	6.2	86.7	......
Perchloric acid	70% aq [b]	0.42	28 [c]	73.1	4.7	16.5
Methane- sulfonic acid	90% [b]	2.7	20 [c]	55.5	38.4	......
Fluoboric acid	48% aq [b]	2.9	20 [c]	35.1	......	64.1
Fluoboric acid	48% aq [b]	1.8	15 [d]	91.5	1.0	......

[a] Isopropylidine glycerol stearate.
[b] Approximate concentration.
[c] Solvent: acetone.
[d] Solvent: 1,4-dioxane.

It is likely that the cyclic structure A and the protonated open form of glycidyl stearate are both present in solution, and that the relative amounts of each depend on the solvent used. The open form which probably predominates in solvents, such as dioxane, acetone, and methanol, reacts with nucleophiles such as water in the manner which is commonly encountered in the acid-catalyzed ring opening of epoxides to give monostearin and analogous products.

The feasibility of the reaction of glycidyl stearate and monostearin was tested by hydrating glycidyl stearate in the presence of an equimolar amount of monoölein, using methyl acetate as solvent. The resulting chromatographed diester fraction contained stearate and oleate in essentially 1:1 ratio (by I.V.). Clearly, then, glycidyl stearate can and does react with a monoglyceride under the conditions of the hydration reaction. Furthermore, although the information just described does not constitute conclusive evidence that the distearin isolated from the hydration of glycidyl stearate is formed in this manner, the suggestion is fairly strong that it indeed is a result of alcoholysis.

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